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## APPENDIX

### Calculation of kinematic viscosity

Using 0%refined palm kernel oil at 40°C

Kinematic viscosity (cSt) = Time (sec.) x Tube's constant

Time = 206 sec., Tube's constant = 0.01678

Kinematic viscosity (cSt) = 206 x 0.01678  
= 3.46 cSt

**Table A-1** Kinematic viscosity of the blends between refined palm kernel oil and high-speed diesel at various temperatures

(a) 40°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0	3.46	3.46	3.46	3.46	0.000
2	3.74	3.73	3.73	3.73	0.010
4	3.78	3.79	3.78	3.78	0.010
6	3.86	3.88	3.88	3.87	0.010
8	4.13	4.13	4.13	4.13	0.000
10	4.43	4.41	4.41	4.42	0.010
100	34.18	33.93	34.18	34.10	0.147

(b) 50°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0	3.07	3.07	3.07	3.07	0.000
2	3.14	3.14	3.14	3.14	0.000
4	3.17	3.17	3.17	3.17	0.000
6	3.37	3.39	3.39	3.38	0.010
8	3.49	3.49	3.49	3.49	0.000
10	3.59	3.59	3.59	3.59	0.000
100	25.00	25.00	25.00	25.00	0.000

(c) 60°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0	2.58	2.58	2.58	2.58	0.000
2	2.62	2.62	2.62	2.62	0.000
4	2.75	2.75	2.75	2.75	0.000
6	2.85	2.85	2.85	2.85	0.000
8	2.94	2.94	2.94	2.94	0.000
10	3.15	3.15	3.15	3.15	0.000
100	19.39	19.39	19.39	19.39	0.000

(d) 70°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0	2.18	2.18	2.18	2.18	0.000
2	2.20	2.20	2.20	2.20	0.000
4	2.27	2.27	2.28	2.27	0.010
6	2.37	2.38	2.37	2.37	0.010
8	2.43	2.43	2.43	2.43	0.000
10	2.47	2.47	2.47	2.47	0.000
100	14.80	14.80	14.80	14.80	0.000

(e) 80°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0	1.85	1.85	1.85	1.85	0.000
2	1.93	1.93	1.93	1.93	0.000
4	2.03	2.03	2.03	2.03	0.000
6	2.10	2.10	2.10	2.10	0.000
8	2.18	2.18	2.18	2.18	0.000
10	2.25	2.25	2.25	2.25	0.000
100	11.48	11.48	11.48	11.48	0.000

**Table A-2** Kinematic viscosity of the blends between refined palm oil and high-speed diesel at various temperatures

(a) 40°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0.00	3.84	3.84	3.84	3.84	0.00
0.05	4.02	4.02	4.02	4.02	0.00
0.10	4.05	4.05	4.05	4.05	0.00
0.15	4.08	4.08	4.08	4.08	0.00
0.20	4.14	4.14	4.14	4.14	0.00
100.00	47.19	47.19	47.19	47.19	0.00

(b) 50°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0.00	3.12	3.12	3.12	3.12	0.00
0.05	3.16	3.16	3.16	3.16	0.00
0.10	3.19	3.19	3.19	3.19	0.00
0.15	3.22	3.22	3.22	3.22	0.00
0.20	3.23	3.23	3.23	3.23	0.00
100.00	32.14	32.14	32.14	32.14	0.00

(c) 60°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0.00	2.62	2.62	2.62	2.62	0.00
0.05	2.62	2.62	2.62	2.62	0.00
0.10	2.65	2.65	2.65	2.65	0.00
0.15	2.66	2.66	2.66	2.66	0.00
0.20	2.68	2.68	2.68	2.68	0.00
100.00	23.47	23.47	23.47	23.47	0.00

(d) 70°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0.00	2.20	2.20	2.20	2.20	0.00
0.05	2.25	2.25	2.25	2.25	0.00
0.10	2.26	2.26	2.26	2.26	0.00
0.15	2.28	2.28	2.28	2.28	0.00
0.20	2.28	2.28	2.28	2.28	0.00
100.00	17.86	17.86	17.86	17.86	0.00

(e) 80°C

%volume of refined palm kernel oil	Kinematic viscosity (cSt)			Average (cSt)	STDEV
	1	2	3		
0.00	1.89	1.89	1.89	1.89	0.00
0.05	1.89	1.89	1.89	1.89	0.00
0.10	1.89	1.89	1.89	1.89	0.00
0.15	1.92	1.92	1.92	1.92	0.00
0.20	1.92	1.92	1.92	1.92	0.00
100.00	14.03	14.03	14.03	14.03	0.00

**Table A-3** Surface tension of the blends between refined palm kernel oil and high-speed diesel at various temperatures

(a) 40°C

%volume of refined palm kernel oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0	28.10	28.20	28.10	28.13	0.058
2	28.20	28.20	28.20	28.20	0.000
4	28.20	28.20	28.20	28.20	0.000
6	28.20	28.20	28.20	28.20	0.000
8	28.20	28.20	28.20	28.20	0.000
10	28.40	28.30	28.40	28.37	0.058
100	31.70	31.60	31.70	31.67	0.058

(b) 50°C

%volume of refined palm kernel oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0	27.40	27.30	27.40	27.37	0.058
2	27.60	27.60	27.60	27.60	0.000
4	27.70	27.70	27.70	27.70	0.000
6	27.70	27.70	27.70	27.70	0.000
8	27.70	27.70	27.70	27.70	0.000
10	27.70	27.70	27.70	27.70	0.000
100	31.00	31.00	31.00	31.00	0.000

(c) 60°C

%volume of refined palm kernel oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0	26.40	26.40	26.40	26.40	0.000
2	26.60	26.60	26.60	26.60	0.000
4	26.70	26.70	26.70	26.70	0.000
6	26.60	26.60	26.60	26.60	0.000
8	26.80	26.80	26.80	26.80	0.000
10	26.70	26.70	26.70	26.70	0.000
100	30.40	30.40	30.40	30.40	0.000

(d) 70°C

%volume of refined palm kernel oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0	25.90	25.90	25.90	25.90	0.000
2	25.90	26.00	26.00	25.97	0.058
4	26.20	26.20	26.20	26.20	0.000
6	26.10	26.10	26.00	26.07	0.058
8	26.20	26.20	26.20	26.20	0.000
10	26.10	26.10	26.10	26.10	0.000
100	29.90	29.90	29.90	29.90	0.000

(e) 80°C

%volume of refined palm kernel oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0	25.10	25.10	25.00	25.07	0.058
2	25.30	25.30	25.30	25.30	0.000
4	25.40	25.40	25.40	25.40	0.000
6	25.50	25.50	25.50	25.50	0.000
8	25.30	25.30	25.30	25.30	0.000
10	25.40	25.40	25.40	25.40	0.000
100	29.30	29.30	29.30	29.30	0.000

**Table A-4** Surface tension of the blends between refined palm oil and high-speed diesel at various temperatures

(a) 40°C

%volume of refined palm oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0.00	28.20	28.20	28.20	28.20	0.000
0.05	28.20	28.20	28.20	28.20	0.000
0.10	28.20	28.20	28.20	28.20	0.000
0.15	28.30	28.30	28.30	28.30	0.000
0.20	28.30	28.30	28.30	28.30	0.000
100.00	32.90	32.90	32.90	32.90	0.000

(b) 50°C

%volume of refined palm oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0.00	27.30	27.30	27.30	27.30	0.000
0.05	27.30	27.30	27.30	27.30	0.000
0.10	27.40	27.40	27.40	27.40	0.000
0.15	27.40	27.40	27.40	27.40	0.000
0.20	27.40	27.40	27.40	27.40	0.000
100.00	32.50	32.40	32.40	32.43	0.058



(c) 60°C

%volume of refined palm oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0.00	26.50	26.50	26.50	26.50	0.000
0.05	26.50	26.50	26.50	26.50	0.000
0.10	26.60	26.60	26.60	26.60	0.000
0.15	26.60	26.60	26.60	26.60	0.000
0.20	26.80	26.80	26.80	26.80	0.000
100.00	31.60	31.60	31.60	31.60	0.000

(d) 70°C

%volume of refined palm oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0.00	25.80	25.80	25.80	25.80	0.000
0.05	25.80	25.80	25.80	25.80	0.000
0.10	26.00	26.00	26.00	26.00	0.000
0.15	26.00	26.00	26.00	26.00	0.000
0.20	26.00	26.00	26.00	26.00	0.000
100.00	30.90	30.90	30.90	30.90	0.000

(e) 80°C

%volume of refined palm oil	Surface tension (mN/m)			Average (mN/m)	STDEV
	1	2	3		
0.00	25.00	25.00	25.00	25.00	0.000
0.05	25.00	25.00	25.00	25.00	0.000
0.10	25.00	25.00	25.00	25.00	0.000
0.15	25.00	25.00	25.00	25.00	0.000
0.20	25.00	25.00	25.00	25.00	0.000
100.00	30.20	30.20	30.20	30.20	0.000

**Table A-5** Specific gravity of the blends between refined palm kernel oil and high-speed diesel at various temperatures

(a) 40°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0	0.8050	0.8050	0.8050	0.8050	0.000
2	0.8100	0.8100	0.8100	0.8100	0.000
4	0.8100	0.8100	0.8100	0.8100	0.000
6	0.8150	0.8150	0.8150	0.8150	0.000
8	0.8150	0.8150	0.8150	0.8150	0.000
10	0.8200	0.8200	0.8200	0.8200	0.000
100	0.9050	0.9050	0.9050	0.9050	0.000

(b) 50°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0	0.8050	0.8050	0.8050	0.8050	0.000
2	0.8050	0.8050	0.8050	0.8050	0.000
4	0.8100	0.8100	0.8100	0.8100	0.000
6	0.8100	0.8100	0.8100	0.8100	0.000
8	0.8100	0.8100	0.8100	0.8100	0.000
10	0.8150	0.8150	0.8150	0.8150	0.000
100	0.8950	0.8950	0.8950	0.8950	0.000

(c) 60°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0	0.8000	0.8000	0.8000	0.8000	0.000
2	0.8025	0.8025	0.8025	0.8025	0.000
4	0.8025	0.8025	0.8025	0.8025	0.000
6	0.8050	0.8050	0.8050	0.8050	0.000
8	0.8050	0.8050	0.8050	0.8050	0.000
10	0.8075	0.8075	0.8075	0.8075	0.000
100	0.8900	0.8900	0.8900	0.8900	0.000

(d) 70°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0	0.7900	0.7900	0.7900	0.7900	0.000
2	0.7950	0.7950	0.7950	0.7950	0.000
4	0.7950	0.7950	0.7950	0.7950	0.000
6	0.7975	0.7975	0.7975	0.7975	0.000
8	0.8000	0.8000	0.8000	0.8000	0.000
10	0.8000	0.8000	0.8000	0.8000	0.000
100	0.8800	0.8800	0.8800	0.8800	0.000

(e) 80°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0	0.7900	0.7900	0.7900	0.7900	0.000
2	0.7900	0.7900	0.7900	0.7900	0.000
4	0.7900	0.7900	0.7900	0.7900	0.000
6	0.7950	0.7950	0.7950	0.7950	0.000
8	0.7975	0.7975	0.7975	0.7975	0.000
10	0.7975	0.7975	0.7975	0.7975	0.000
100	0.8750	0.8750	0.8750	0.8750	0.000

**Table A-6** Specific gravity of the blends between refined palm oil and high-speed diesel at various temperatures

(a) 40°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0.00	0.8100	0.8100	0.8100	0.8100	0.000
0.05	0.8100	0.8100	0.8100	0.8100	0.000
0.10	0.8100	0.8100	0.8100	0.8100	0.000
0.15	0.8100	0.8100	0.8100	0.8100	0.000
0.20	0.8100	0.8100	0.8100	0.8100	0.000
100.00	0.8950	0.8950	0.8950	0.8950	0.000

(b) 50°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0.00	0.8050	0.8050	0.8050	0.8050	0.000
0.05	0.8050	0.8050	0.8050	0.8050	0.000
0.10	0.8050	0.8050	0.8050	0.8050	0.000
0.15	0.8050	0.8050	0.8050	0.8050	0.000
0.20	0.8050	0.8050	0.8050	0.8050	0.000
100.00	0.8875	0.8875	0.8875	0.8875	0.000

(c) 60°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0.00	0.7975	0.7975	0.7975	0.7975	0.000
0.05	0.7975	0.7975	0.7975	0.7975	0.000
0.10	0.7975	0.7975	0.7975	0.7975	0.000
0.15	0.7975	0.7975	0.7975	0.7975	0.000
0.20	0.7975	0.7975	0.7975	0.7975	0.000
100.00	0.8800	0.8800	0.8800	0.8800	0.000

(d) 70°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0.00	0.7900	0.7900	0.7900	0.7900	0.000
0.05	0.7900	0.7900	0.7900	0.7900	0.000
0.10	0.7900	0.7900	0.7900	0.7900	0.000
0.15	0.7900	0.7900	0.7900	0.7900	0.000
0.20	0.7900	0.7900	0.7900	0.7900	0.000
100.00	0.8750	0.8750	0.8750	0.8750	0.000

(e) 80°C

%volume of refined palm kernel oil	Specific gravity			Average	STDEV
	1	2	3		
0.00	0.7850	0.7850	0.7850	0.7850	0.000
0.05	0.7850	0.7850	0.7850	0.7850	0.000
0.10	0.7850	0.7850	0.7850	0.7850	0.000
0.15	0.7850	0.7850	0.7850	0.7850	0.000
0.20	0.7850	0.7850	0.7850	0.7850	0.000
100.00	0.8650	0.8650	0.8650	0.8650	0.000

**Calculation of Oh and Re<sub>L</sub>**

2 vol% of refined palm kernel oil blends at 40°C,  $d_0 = 0.2$  mm, horse power = 80HP, BSFC = 0.5 and duty cycle = 0.9

$$Oh = \frac{\mu_L}{\sqrt{\rho_L \sigma d_0}} \quad (A.1)$$

where Oh = Ohnesorge number

$\mu_L$  = Viscosity of the blends (kg/m·s)

$\rho_L$  = Density of the blends (kg/m<sup>3</sup>)

$\sigma$  = Surface tension of the blends (mN/m)

$d_0$  = Diameter of hole injector (m)

$$oh = \frac{3.46}{\sqrt{803.69 \times 28.2 \times 0.2 \times 10^{-3}}}$$

$$= 1.63$$

$$Re_L = \frac{\rho_L U_L d_0}{\mu_L} \quad (A.2)$$

where  $U_L$  = Velocity at the injector exit (m/s)

$$U_L \text{ (m/s)} = \frac{U_L \text{ (lbs/hr)} \times \rho_L}{3600 \times 2.2 \times \pi r^2} \quad (A.3)$$

$$U_L(\text{lbs/hr}) = \frac{\text{HP} \times \text{BSFC}}{\text{no. of injector} \times \text{duty cycle}} \quad (\text{A.4})$$

$$U_L(\text{lbs/hr}) = \frac{80 \times 0.5}{4 \times 0.9}$$

$$= 11.11 \text{ lbs/hr}$$

$$U_L(\text{m/s}) = \frac{11.11 \times 803.69}{3600 \times 2.2 \times \pi \times (0.1 \times 10^{-3})^2}$$

$$= 3.57 \times 10^7 \text{ m/s}$$

so,

$$\text{Re}_L = \frac{803.69 \times 3.57 \times 10^7 \times 0.2 \times 10^{-3}}{3.46}$$

$$= 1.65 \times 10^6$$

**Table A-7** Composition of palm kernel oil and palm oil

<b>Composition</b>	<b>Palm kernel oil</b>	<b>Palm oil</b>
C8	1.4	-
C10	2.9	-
C12	50.9	0.3
C14	18.4	1.1
C16	8.7	42.9
C16:1	-	0.2
C17:1	-	0.1
C18	1.9	4.6
C18:1	14.6	39.3
C18:2	-	10.7
C18:3	1.2	-
C18:4	-	0.4
C20	-	0.3
C22	-	0.1

## CURRICULUM VITAE

**Name:** Ms. Naramas Hitaphan  
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